Architecture Studies Done for High-Rate Duplex Direct Data Distribution (D4) Services

A study was sponsored to investigate a set of end-to-end system concepts for implementing a high-rate duplex direct data distribution (D4) space-to-ground communications link. The NASA Glenn Research Center is investigating these systems (both commercial and Government) as a possible method of providing a D4 communications service between NASA spacecraft in low Earth orbit and the respective principal investigators using or monitoring instruments aboard these spacecraft. Candidate commercial services were assessed regarding their near-term potential to provide a D4 type of service. The candidates included K-band and V-band geostationary orbit and nongeostationary orbit satellite relay services and direct downlink (D3) services. Internet protocol (IP) networking technologies were evaluated to enable the user-directed distribution and delivery of science data. Four realistic, near-future concepts were analyzed:

1. A duplex direct link (uplink plus downlink communication paths) between a low-Earth-orbit spacecraft and a principal-investigator-based autonomous Earth station
2. A space-based relay using a future K-band nongeosynchronous-orbit system to handle both the uplink and downlink communication paths
3. A hybrid link using both direct and relay services to achieve full duplex capability
4. A dual-mode concept consisting of both a duplex direct link and a space relay duplex link operating independently

The concepts were analyzed in terms of contact time between the NASA spacecraft and the communications service and the achievable data throughput. Throughput estimates for the D4 systems were based on the infusion of advanced communications technology products (single and multibeam K-band phased-arrays and digital modems) being developed by Glenn. Cost estimates were also performed using extrapolated information from both terrestrial and current satellite communications providers. The throughput and cost estimates were used to compare the concepts.

THROUGHPUT COMPARISON FOR SPACECRAFT IN INTERNATIONAL SPACE STATION ORBIT

	D4 single beam (K-band)	D4 dual beam (K-band)	Commercial X-band downlink service
Phased-array antenna beam scan, deg	50	42	50
Return link data rate, Mbps	622	1244	300
Average contact time per day, sec	337	178	337
Throughput per day, Gbits	210	221	101
Estimated cost per Gbit received	$0.13 to $0.40	$0.09 to $0.29	$0.28 to $0.83

Throughput and cost information were compiled for a number of possible D3/D4 architectures using both currently available Government and commercial X-band and K-band services. Contact times were calculated for NASA low-Earth-orbit spacecraft at two different orbital inclinations, one for the International Space Station and one for polar orbiters. The table presents throughput results for three different cases at the space station's orbital inclination.

The service categories shown in columns two and three represent possible D4 service between spacecraft in low Earth orbit and the ground station using two different types of space-based transmitters in both simple duplex and relay configurations. As shown in column two, a duplex link using a single-beam phased array develops an average throughput of 210 Gbits per day, whereas a dual-beam phased array can average 221 Gbits per day (column three). Column four presents the average throughput of commercial services currently being used by NASA for direct-to-ground service. As shown, K-band services can provide greater average throughput at lower costs than the X-band service currently used.

Note that the throughput results for columns two to four are based on a 10-day average of contact times for four different ground station locations in the continental United States. Among the possible architectures, the most promising is the dual-mode combination. The dual-mode architecture combines a simplex high-data-rate direct downlink, using the user datagram protocol (UDP) instead of transmission control protocol (TCP), combined with a low-data-rate, full-duplex TCP/IP link using a satellite communications service such as Inmarsat or the Tracking and Data Relay Satellite System (TDRSS) Multiple Access. The high-data-rate link would be used for returning latency-tolerant instrument data from the spacecraft. The low-data-rate link would be used for real-time interactive commands between the principal investigator and the spacecraft and would be available all the time, instead of only when the spacecraft was in view. Copies of the study can be requested from Lawrence Wald, project manager.

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